# METHODS TO VERIFY ABSORBED DOSE OF IRRADIATED CONTAINERS AND EVALUATION OF DOSIMETERS

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**Abstract.** The research on dose distribution in irradiated food containers and evaluation of several methods to verify absorbed dose were carried out. The minimum absorbed dose of treated five orange containers was in the top of the highest or in the bottom of lowest container. $D_{max}/D_{min}$ in this study was 1.45 irradiated in a commercial $^{60}Co$ facility. The density of orange containers was about 0.391g/cm$^3$. The evaluation of dosimeters showed that the PMMA-YL and clear PMMA dosimeters have linear relationship with dose response, and the word NOT in STERIN-125 and STERIN-300 indicators were covered completely at the dosage of 125 and 300 Gy respectively.

## INTRODUCTION

Agricultural exports including fresh and dry fruits and tree nuts provide important sources of foreign exchange for many developing countries. But the major importing countries such as Australia, Japan and USA have strict regulations for plant protection and quarantine. With the ban of ethylene dibromide in 1980s and limited use of methyl bromide in the near future, the two main fumigants used for controlling insect infestation including quarantine purposes, countries which depend on fumigation to overcome trade barriers in fresh fruits and other agricultural products will have to search urgently for alternative treatments to maintain their trade[1]. Irradiation, as one of the alternative treatment, is being increasingly recognized by authorities and organizations as an effective method for insect disinfestation of quarantine treatment[2]. The studies on quality control of irradiation especially methods to verify the absorbed minimum dose in irradiated food containers is needed[3,4].

## MATERIALS AND METHODS

**Materials**: Orange containers were bought from market in November. PMMA-YL dosimeter, developed by Dr. Tang of the Institute for Application of Atomic Energy; clear PMMA sheets were supplied by the Pak Poly Industries (Pvt) Limited, Pakistan; STERIN indicators were provided by STERIN company, USA.

$^{60}Co$ irradiation source in Irradiation Center of the Institute for Application of Atomic Energy was used for irradiation treatment. UVVIS Spectrophotometer WFZ800D3A was used for measuring the optical density of the dosimeters.

Dose distribution in irradiated orange containers: Dose distribution in irradiated orange containers was measured as follows in 1995: A total of 66 PMMA-YL dosimeters were placed in five orange containers together with standard Fricke dosimeter, 3 in a row. Nos 1–9, 19–24, 31–36, 43–48, 55–60 dosimeters were attached in one side of the container. Dosimeters Nos 10–18, 25–30, 37–42, 49–54, 61–66 were placed in the middle of the container. Dosimeters Nos 14, 26, 38, 50 and 62 were in the center of container 1, 2, 3, 4 and 5 (Figure 1). Five containers were placed played in a row, with container 1 on the top and container 5 on the bottom. The samples were irradiated static by $^{60}Co$ irradiator. The absorbed dose were planned to be 150 Gy.

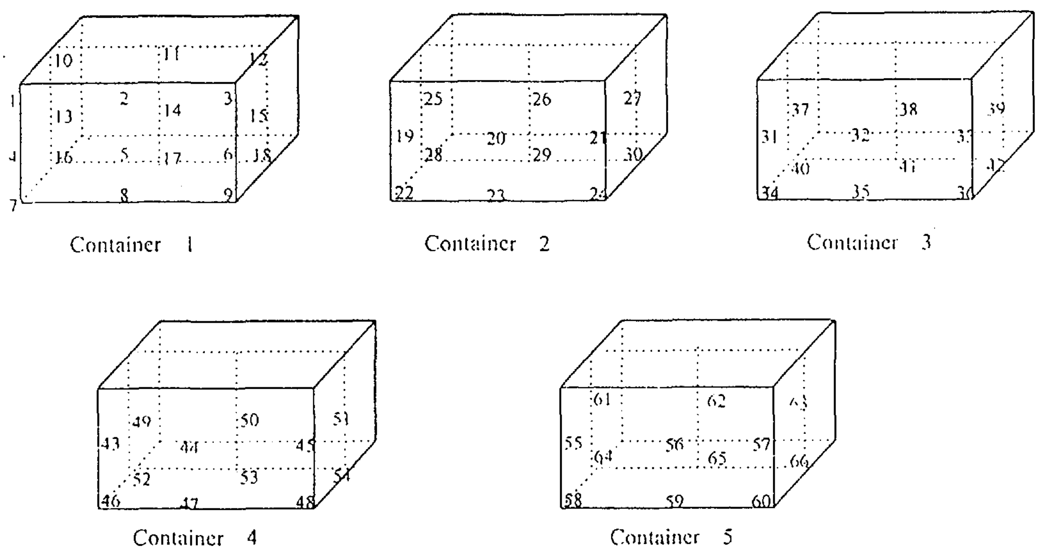


*FIG. 1 Dosimeters position (166) in standardized orange containers, 1995.*

Density of orange containers: oranges were packaged in paper cartons. The size of carton was 42 × 32 × 33 $cm^3$ .

The containers were turned 180° once during irradiation. The optical density of PMMA-YL dosimeter were measured at 530 nm before and after irradiation. The Fricke dosimeter was prepared and measured by standard method[5].

Density of orange containers: oranges were packaged by paper cartons. The size of carton was 42×32×33 $cm^3$.

**Evaluation of dosimeters**

1. Evaluation of PMMA dosimeter: PMMA-YL is a narrow strip of 10×40 $mm^2$ and 13 mm thickness. The color of dosimeter changes from yellow to red or dark red after irradiation, The wave length of 530 nm was used for the measurement. The dose range was 50–1000 Gy. The clear PMMA dosimeters include five sheets of 11×30 $mm^2$ pieces in 2, 4, 6, 8 and 10 mm thickness which are to be studied at dose level of 0.1–1.0 kGy.

Dose response of PMMA dosimeter: Six pieces of PMMA-YL dosimeters were irradiated at doses of 75, 100, 150, 200, 250 and 300 Gy in a $^{60}$Co Gamma source. The thickness of dosimeters was 2.39–2.40 mm. Fricke dosimeter which was graduated by National Metrology Institute, was used as standard for calibration. The optical density of PMMA-YL dosimeter was measured at 530 nm before and after irradiation with spectrophotometer.

Six pieces of clear PMMA dosimeters were irradiated at doses of 100, 200, 300, 400 and 500 Gy in the $^{60}$Co Gamma source. The thickness of dosimeters was 4.0 mm. The optical density of clear PMMA dosimeter was measured at 320 nm before and after irradiation with spectrophotometer.

PMMA dosimeters stored at different humidity: Out of ten pieces each of thickness 3.42–3.43 mm of PMMA-YL dosimeters and 4 mm of clear PMMA dosimeters, two each were kept in different containers filled with different proportions of glycerine and water to obtain the relative humidity of 60%, 71%, 80%, 91% and 94%. These dosimeters were irradiated at the dose rate of 2.0 Gy/min. The absorbed dose was 300 Gy for PMMA-YL and 500 Gy for clear PMMA. The bottles were stored in dark at room temperature. The optical density of PMMA-YL dosimeter were measured at 530 nm and clear PMMA dosimeter were measured at 320 nm before and after irradiation 0, 9, 43 and 81 days. For avoiding the effects of humidity, the irradiated dosimeters were also packaged in PE plastic bag.

2. Evaluation of STERIN indicators: Two type of indicators were first irradiated by $^{60}Co$ source at a dose rate of 36.2 Gy/min. The dose 75 Gy, 100 Gy and 150 Gy were used for STERIN-125 indicator evaluation and 150 Gy, 300 Gy and 400 Gy for STERIN-300 evaluation. Two samples were irradiated for each treatment.

The STERIN-300 indicators were irradiated by the new irradiator in our institute. The indicator was placed with ampoules (Fricke dosimeter), in or out of four containers in one carrier of overhead conveyor system.

## RESULTS

### 1. Dose distribution in irradiated orange containers

The dose distribution in containers filled with orange was measured by PMMA-YL dosimeter and Fricke dosimeter[5]. The results of absorbed dose in 66 points of five containers are listed in Table 1. The results of two dosimeters were almost the same. The lowest absorbed dose were in position Nos 10,11 and 12, the top middle of container 1 and the bottom of container 5. The highest dose was in the sides of container 2, 3 and 4. $D_{max}/D_{min}$ were 1.34 from the data of Fricke dosimeter and 1.53 from the data of PMMA-YL dosimeter.

According to the practical guide of dosimetry for food processing[6], for static irradiation, at least one dosimeter is needed for one batch of treated food product. In our experiment, if one dosimeter was placed at position 9 (Figure 1), the lowest absorbed dose in these five containers will be: Absorbed dose at position 9 × R, where, R is the lowest absorbed doses in containers/absorbed dose at position 9 = 157.6/188.8 = 0.835.

The weight of five orange containers were 17.1 kg 17.3 kg, 16.8 kg, 17.1 kg and 17.4 kg respectively. The volume of container was 42 × 32 × 33 $cm^3$. The density of orange containers was about 0.379 $g/cm^3$.

### 2. Evaluation of dosimeters

1. Evaluation of PMMA dosimeters: The dose response of PMMA-YL dosimeter is shown in Fig. 2. The coordinate curve shows the straight line relationship between the absorptive dosage and the optical density (OD) of the dosimeter. The relative coefficient $R^2 = 0.9792$.

The dose response of clear PMMA dosimeter is shown in Fig. 3. The curve shows the straight line relationship between the absorptive dosage and the optical density (OD) of the dosimeter. The relative coefficient $R^2 = 0.9024$.

TABLE 1. DOSE DISTRIBUTION IN ORANGES CONTAINERS MEASURED BY PMMA-YL AND FRICKE DOSIMETER

| No. | Fricke | PMMA-YL | No. | Fricke | PMMA-YL | No. | Fricke | PMMA-YL |
|---|---|---|---|---|---|---|---|---|
| 1 | 182.3 | 187[1] | 23 | 199.5 | 172 | 45 | 202.6 | 214 |
| 2 | 178.1 | 166 | 24 | 202.3 | 169 | 46 | 207.1 | 207 |
| 3 | 179.2 | 161 | 25 | 179.2 | 150 | 47 | 200.0 | 212 |
| 4 | 178.9 | 161 | 26 | 175.0 | 149 | 48 | 209.1 | 213 |
| 5 | 179.2 | 164 | 27 | 174.8 | 151 | 49 | 199.5 | 189 |
| 6 | 178.7 | 167 | 28 | 195.8 | 191 | 50 | 186.0 | 173 |
| 7 | 186.0 | 160 | 29 | 193.9 | 177 | 51 | 183.2 | 171 |
| 8 | 182.3 | 164 | 30 | 195.3 | 181 | 52 | 183.8 | 178 |
| 9 | 188.8 | 167 | 31 | 205.4 | 210 | 53 | 184.0 | 170 |
| 10 | 157.0 | 145 | 32 | 200.3 | 192 | 54 | 184.6 | 190 |
| 11 | 157.6 | 144 | 33 | 209.6 | 208 | 55 | 185.7 | 200 |
| 12 | 157.9 | 140 | 34 | 210.1 | 211 | 56 | 203.4 | 192 |
| 13 | 167.7 | 147 | 35 | 207.6 | 192 | 57 | 189.1 | 193 |
| 14 | 161.0 | 143 | 36 | 208.2 | 192 | 58 | 181.5 | 185 |
| 15 | 162.7 | 146 | 37 | 187.7 | 167 | 59 | 176.4 | 170 |
| 16 | 179.0 | 151 | 38 | 187.7 | 160 | 60 | 188.2 | 173 |
| 17 | 178.4 | 152 | 39 | 180.9 | 161 | 61 | 164.9 | 174 |
| 18 | 179.8 | 156 | 40 | 197.2 | 196 | 62 | 163.5 | 176 |
| 19 | 197.8 | 179 | 41 | 199.9 | 199 | 63 | 168.3 | 180 |
| 20 | 197.2 | 175 | 42 | 199.8 | 201 | 64 | 163.2 | 153 |
| 21 | 197.8 | 171 | 43 | 201.7 | 201 | 65 | 163.8 | 151 |
| 22 | 202.6 | 180 | 44 | 201.2 | 189 | 66 | 163.8 | 148 |

Note: The data normalized by thickness.

The effects of relative humidity on the optical density of day 0, 9, 43 and 81 are shown in Fig. 4. The optical density changes of irradiated PMMA-YL dosimeters in different humidity was not much influenced by humidity in the experiment, but the optical density in 80% humidity was lower than others. After ten days storage, the optical density was stable at 60% and 71%, but lower at 80%, 91% and 94% humidity. This change was more obvious after 43 days storage and the optical density of 81 days samples was faded with the humidity. The optical density of plastic bag packaged samples showed almost no change, 0.3555 at day 0 and 0.3445 at day 81.

At days 0 and ten days later the optical density of irradiated clear PMMA dosimeters in different humidities showed no regular changes (Table 2).

2. Evaluation of STERIN indicators: The results for STERIN-125 and STERIN-300 indicators irradiated by four different doses were as follows. The STERIN-125 indicators changed to dark red after 75 Gy treatment and NOT word could be recognized clearly. At the dosage of 100 Gy the color of indicator got darker but the word NOT still could be seen. When the irradiation dose at/and more than 125 Gy, the color of indicator was black and the word NOT could not be seen at all. The results for STERIN-300 were similar with STERIN-125. The color of indicator also changed completely at 300 Gy and higher dose. The results were same after six months' storage.

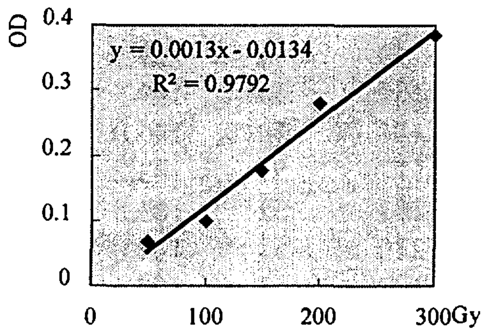


*FIG. 2. Dose response of PMMA-YL dosimeters.*

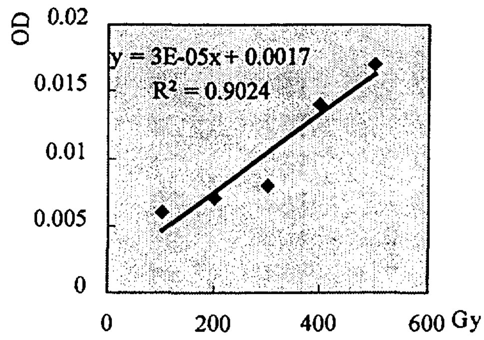


*FIG. 3. Dose response of clear dosimeters.*

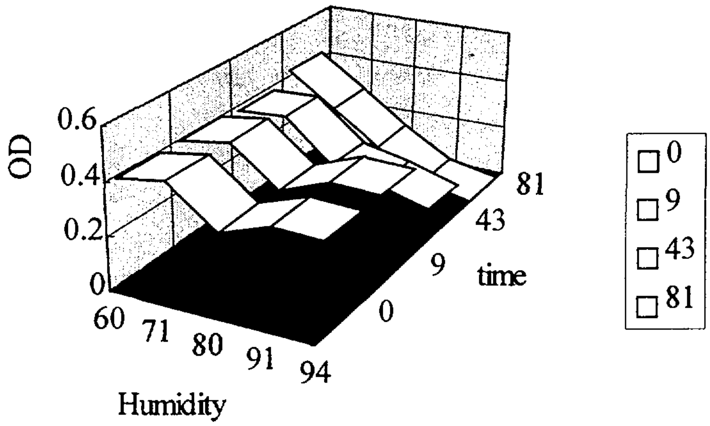


*FIG. 4. The effects of different humidity on storage of irradiated PMMA-YL dosimeters.*

TABLE 2. THE OPTICAL DENSITY CHANGES OF THE CLEAR PMMA DOSIMETERS AT DIFFERENT HUMIDITY AND AFTER 0, 10 DAYS STORAGE

| humidity(%) | 60 | 71 | 80 | 91 | 94 |
|---|---|---|---|---|---|
| 0 day | 0.024 | 0.021 | 0.010 | 0.018 | 0.024 |
| 10 days storage | 0.029 | 0.032 | 0.016 | 0.024 | 0.017 |

The results for STERIN-300 irradiated in and on four containers in one carrier of overhead conveyer system are shown in Table 3. When the absorbed dose measured by Fricke dosimeter was lower than 300 Gy, the NOT word in STERIN-300 indicator were shown clearly. When absorbed dose was higher than 300 Gy, the NOT word in STERIN-300 indicator changed to dark and masked the letter NOT. But the NOT word still could be seen in one position but the Fricke dosimeter there showed the absorbed dose of 332 Gy.

**Conclusion**

The minimum absorbed dose of treated five orange containers was in the top of the containers. $D_{max}/D_{min}$ in this study was 1.451. The dose in a reference position (position 9) could be related to the minimum dose by a factor 0.835.

TABLE 3. IRRADIATION EFFECTS OF STERIN-300

| STERIN-300 | Fricke | STERIN-300 | Fricke | STERIN-300 | Fricke |
|---|---|---|---|---|---|
| ' | 247 | ++ | 398 | ++ | 377 |
| | 254 | ++ | 396 | ++ | 401 |
| | 248 | ++ | 391 | + | 332 |
| ++ | 384 | ++ | 378 | | 264 |
| ++ | 417 | ++ | 394 | | 272 |
| ++ | 376 | ++ | 392 | | 262 |

Note: "" NOT word could be seen clearly.
"++" NOT word could not be seen.
"+" NOT word could be seen but not so clearly.

The evaluation results of two PMMA dosimeters show that the PMMA-YL dosimeter was useful at the 0–300 Gy irradiation. The absorbed dose was not much influenced by the relative humidity of lower than 70% after storage of 10 days. In order to avoid the effects of humidity, the PMMA-YL dosimeter with plastic package was suggested. For clear PMMA dosimeter, it seemed that 0–500 Gy absorbed dose was too low to be measured, the relative coefficient was only 0.9070. STERIN indicator appears to be adequate for a visual identification of 125 or 300 Gy irradiation.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] Loaharanu, P., International trade in irradiated foods: regional status and outlook, Food Technology **43** (7) (1989) 77–80.
[2] FAO/IAEA, Co-ordinated Research Programmes, Food Irradiation Newsletter 8(2) (1986) 14–27.
[3] Thakur, B.R., Singh, R.O., Combination Processed in Food Irradiation, Trends in Food Science & Technology Vol. 6 (1995).
[4] Heather, N.W., Irradiation as a Quarantine Treatment of Agricultural Commodities Against Arthropod Pest IAEA-SM-327/58, IAEA, Vienna (1994) 627–639.
[5] Standard Method for Using the Ferrous Sulfate (Fricke) Dosimeter to Measure Absorbed Dose in Water, GB. 1989:13989.
[6] FAO/IAEA, Food Irradiation Newsletter 20(2) (1996) 14–19.